The Impact of Forest Roads on Hydrological Processes and Pathways: A Review of Published Literature

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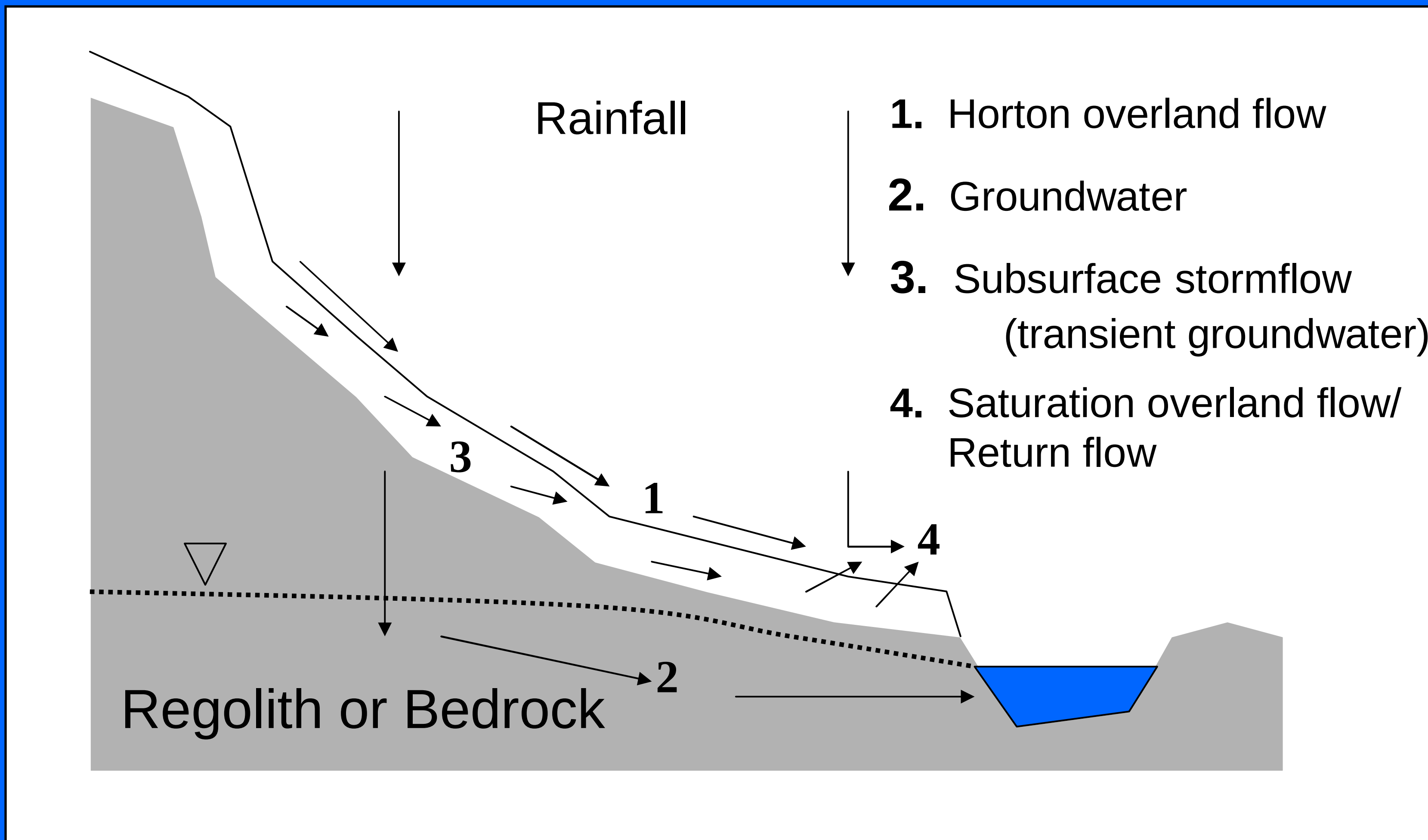
Fundamental Questions Regarding Road Hydrology

- What are the hydrological processes and pathways affected by roads at the hillslope and watershed scales;

- At what spatial and temporal scales are these processes affected (e.g. Are road augmented peak flows a concern?);

- What can be done to mitigate the hydrologic effects of roads?

Hillslope Runoff Processes



(Dunne and Leopold, 1978)

Horton Overland Flow (HOF)

- Infiltration rate << Rainfall rate;
- Common in arid to subhumid climates;
- Thin vegetation;
- Soil disturbance (e.g. compaction);
- **NOT COMMON IN UNDISTURBED FORESTED AREAS.**

Subsurface Stormflow (SSF)

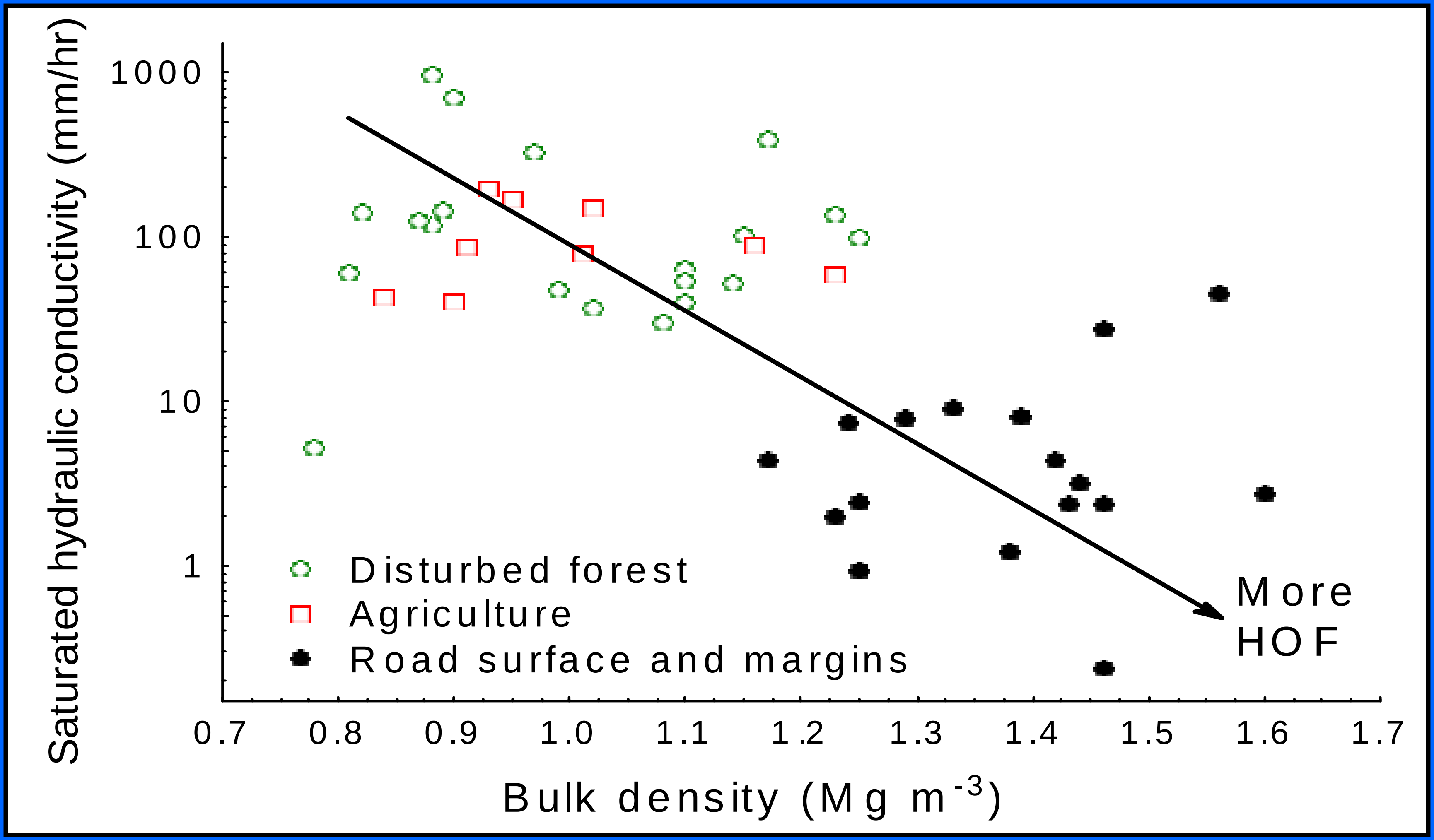
(Hillslope trench; McDonnell, 2005)

- Steep hillslopes
- Permeable soils overlying relatively impermeable bedrock or regolith
- Humid climate w/ abundant vegetation
- **COMMON IN PNW**

Road Surface Hydrology

- Highly compacted;
- High bulk densities;
- Little or no pore space.

Road Surface Hydrology - HOF

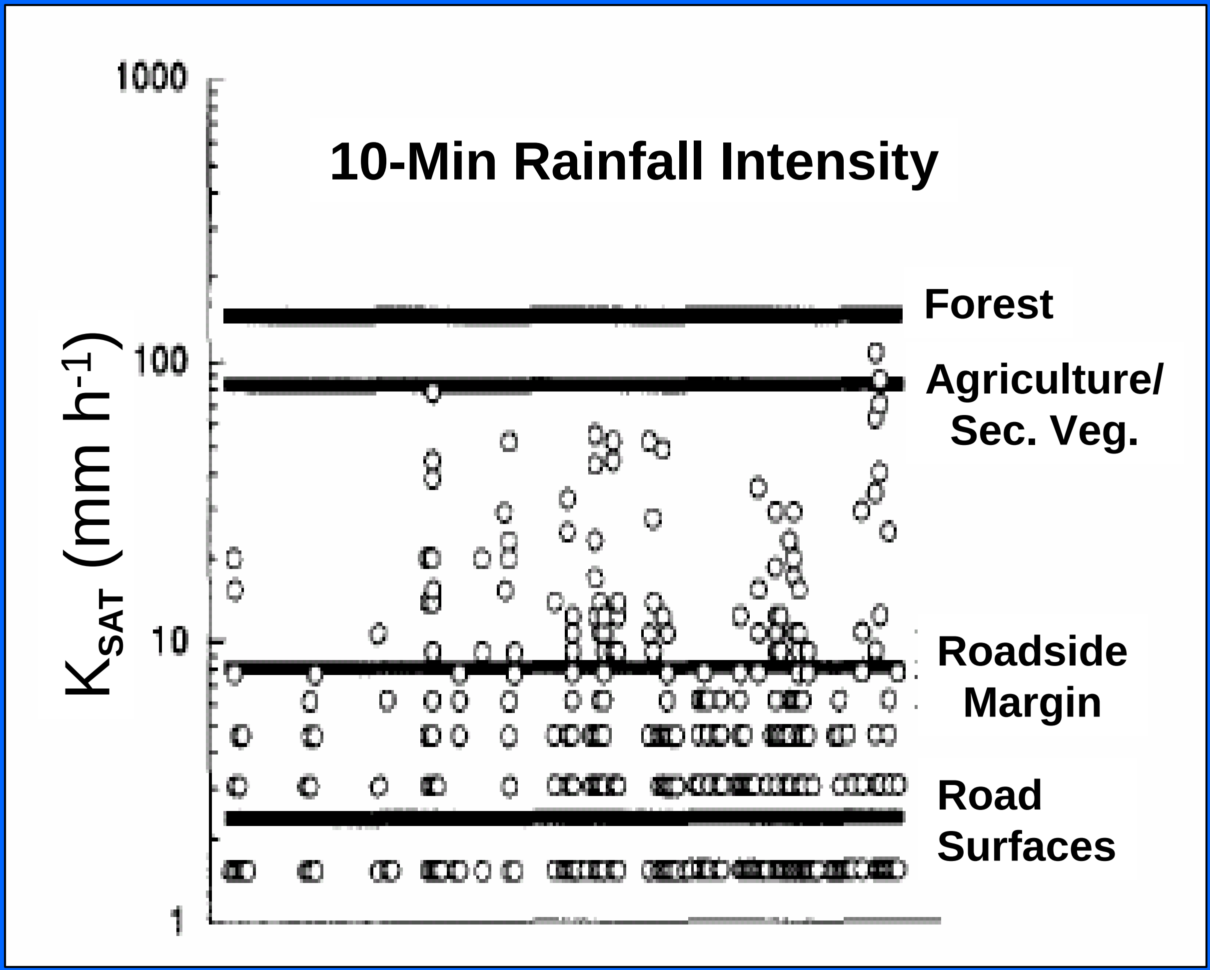


(from Ziegler, 2005)

Road Surface Hydrology - K_{SAT}

K_{SAT} ($mm\ hr^{-1}$)	Location	Reference
0.0036	Oregon C.R.	Loague and Kyriakidis, 1997
0.11	N. Rockies	Luce and Cundy, 1994
0.3	NW. Washington	Reid and Dunne, 1984
2.3	Thailand	Ziegler and Giambelluca, 1997
3.0	Idaho	Luce, 1997
36.5	SE. Australia	Lane and Sheridan, 2002

Road Surface Hydrology



- Have the potential to produce runoff during small storms;
- Abundance of HOF on road surfaces.

(Ziegler and Giambelluca, 1997)

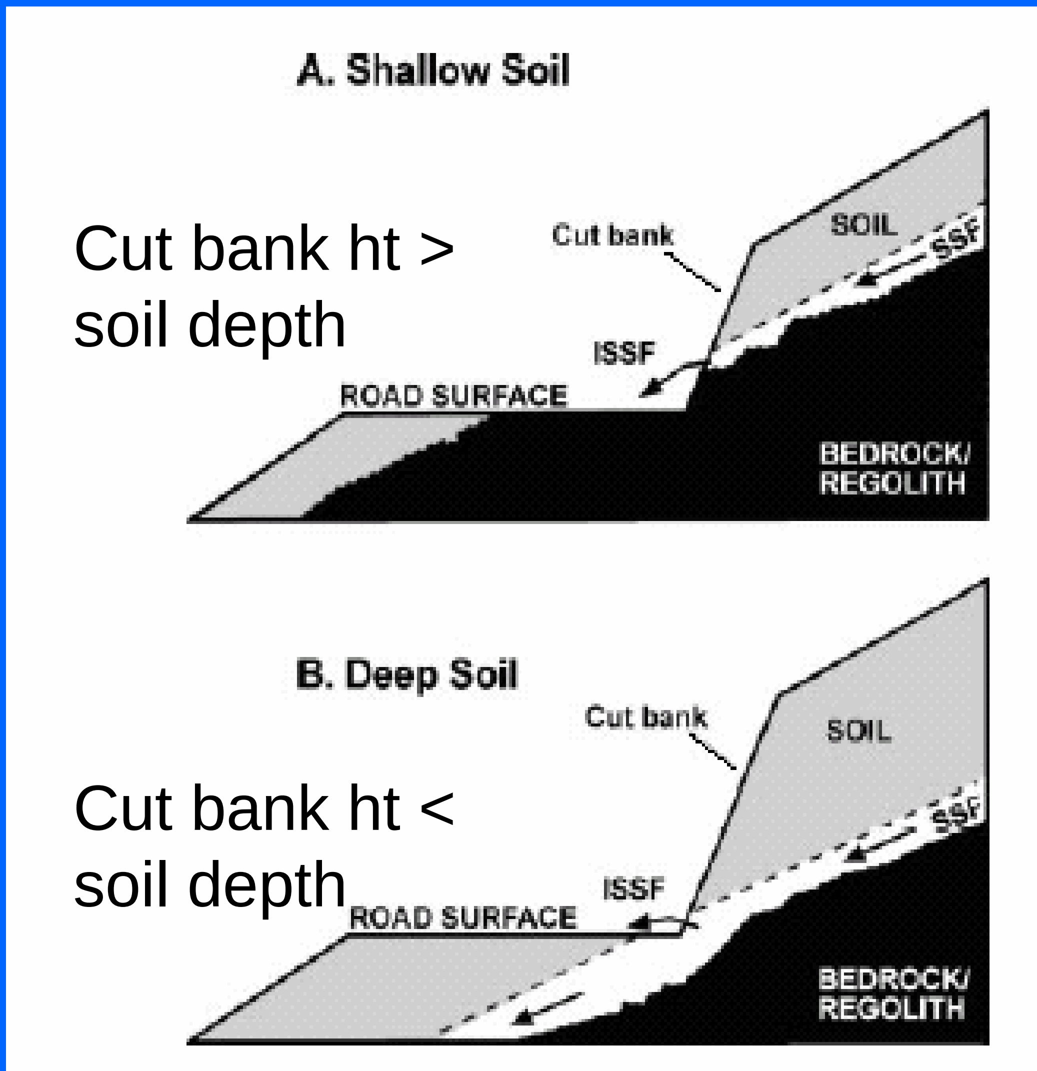
Cutslope Hydrology

- Road cuts can expose soil/bedrock interface;
- Intercepts SSF (ISSF);
- Responsible for up to 95% of total road runoff for PNW (Wemple and Jones, 2003).

Cutslope Hydrology – Impacts on Runoff Timing

- Velocity of HOF is 1-4 orders of magnitude greater than SSF (Dunne, 1978; Hillel, 1998);
- Increases rising limb of hydrograph.

Cutslope Hydrology



- Cut banks intercepts SSF when the cutslope height > soil depth;
- ISSF is less likely on deeper soils, lower slopes, and ridgetops.

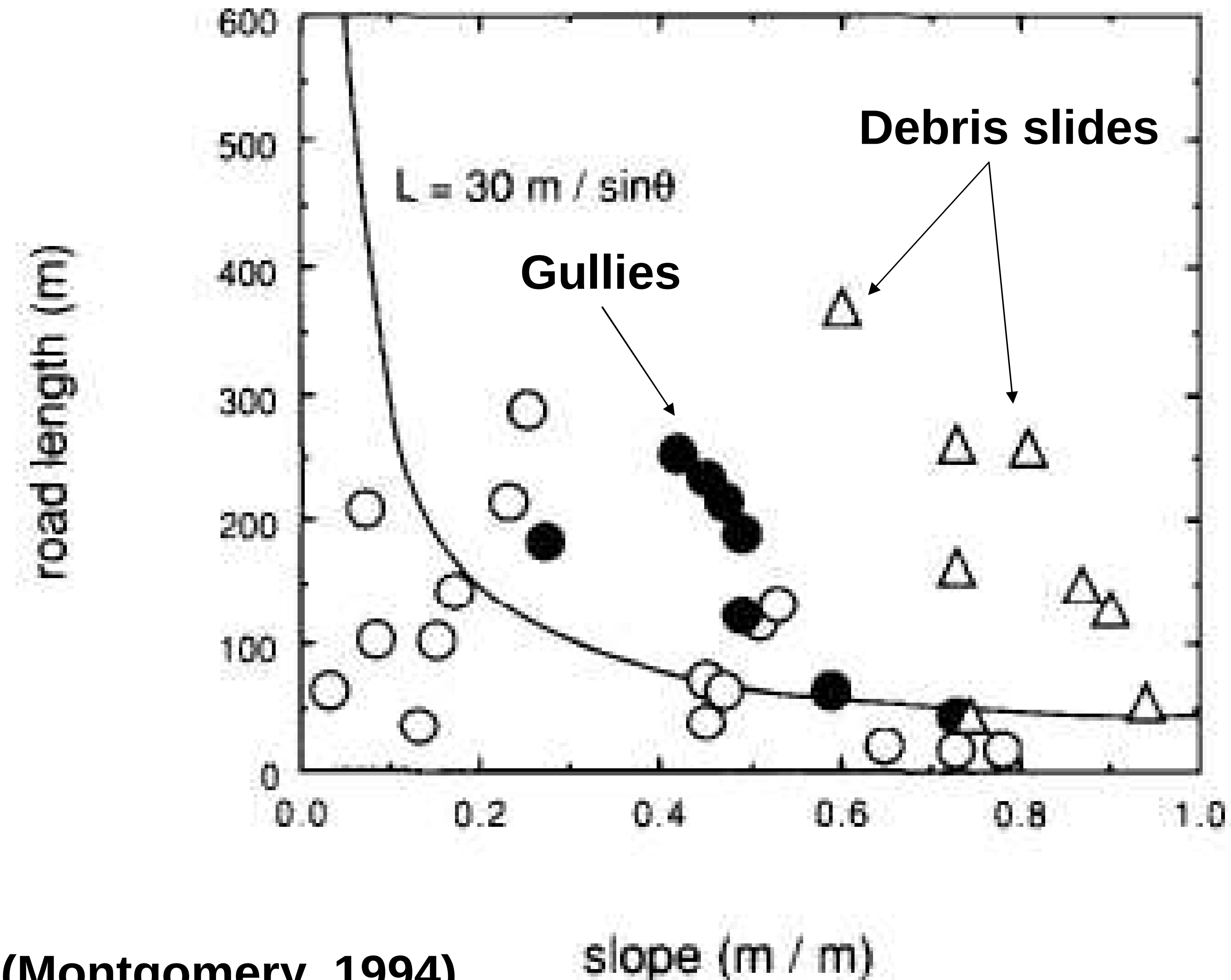
(Ziegler et al., 2002)

Road Segment Hydrology

- Road segments can intercept low order surface waters and reroute water onto the road ditch or road surface (i.e**. PIRACY)**

Road Segment Hydrology

- Combination of HOF, ISSF, and pirated water increase the likelihood of gully and landslide initiation below drainage outlet;

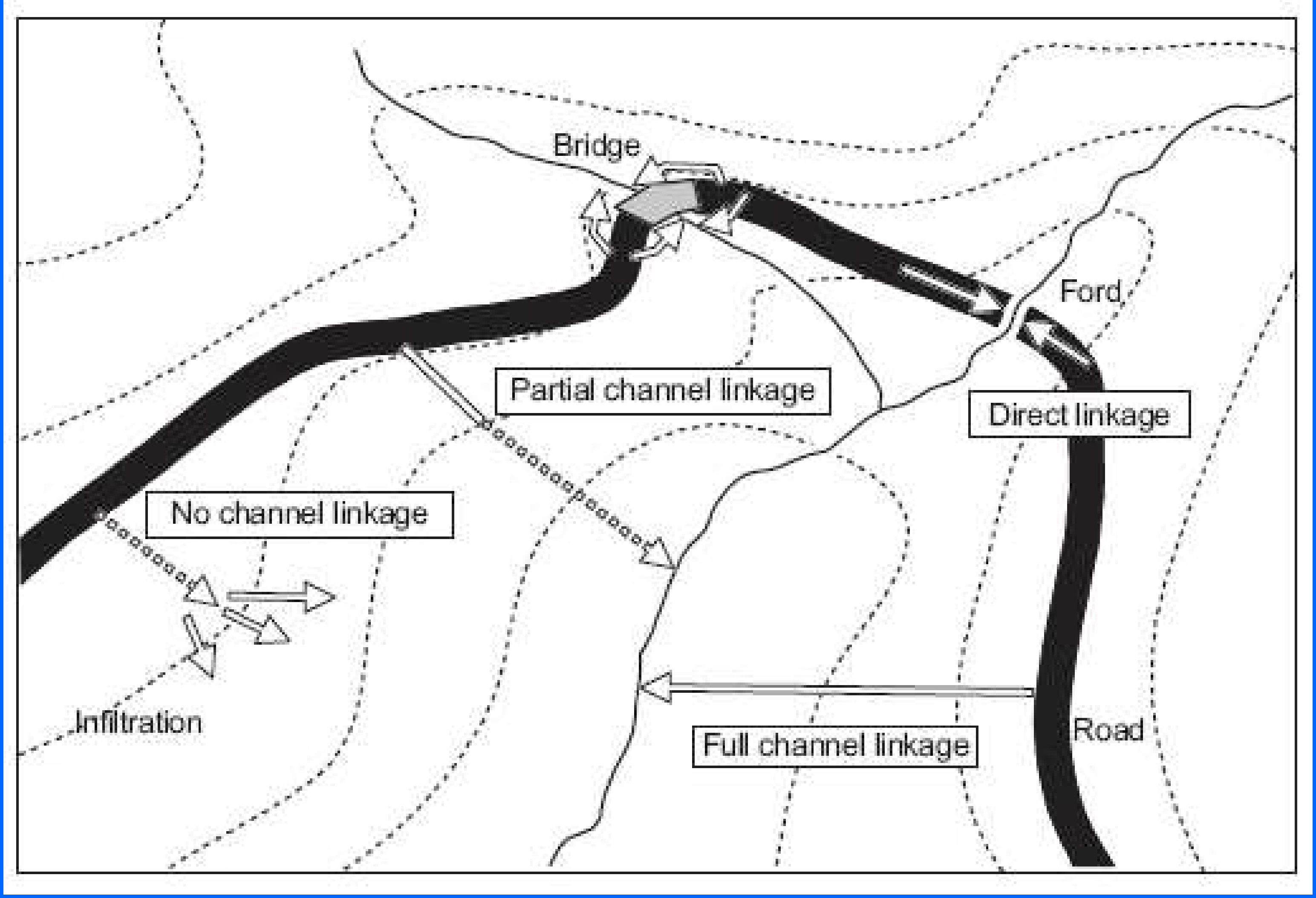


(Montgomery, 1994)

Road Segment Hydrology

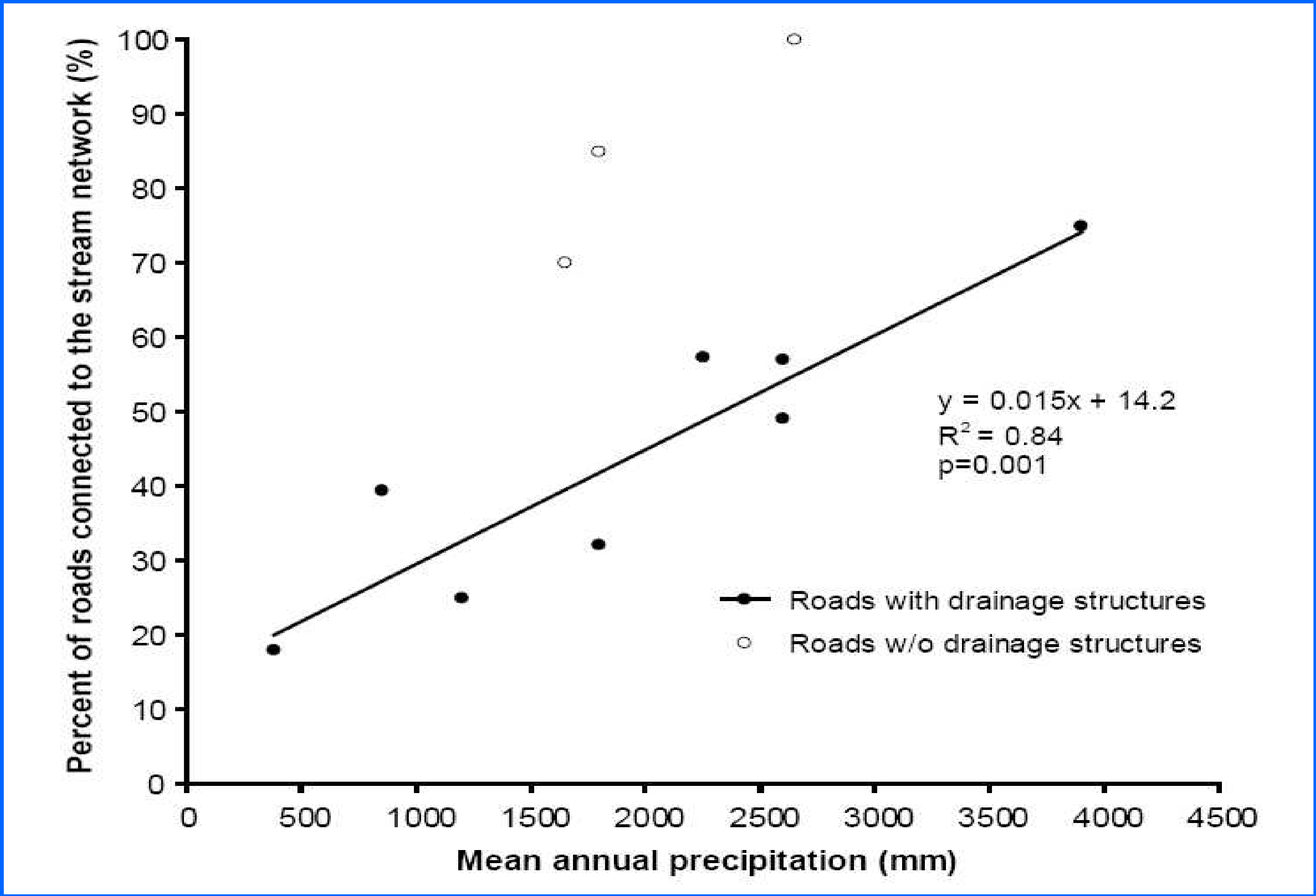
- Road segments can potentially deliver excess runoff to channel network at stream crossings

Road Segment Hydrology – Connectivity to Surface Water



(Croke and Mockler, 2005)

Road Segment Hydrology – Connectivity



(MacDonald and Coe, 2007)

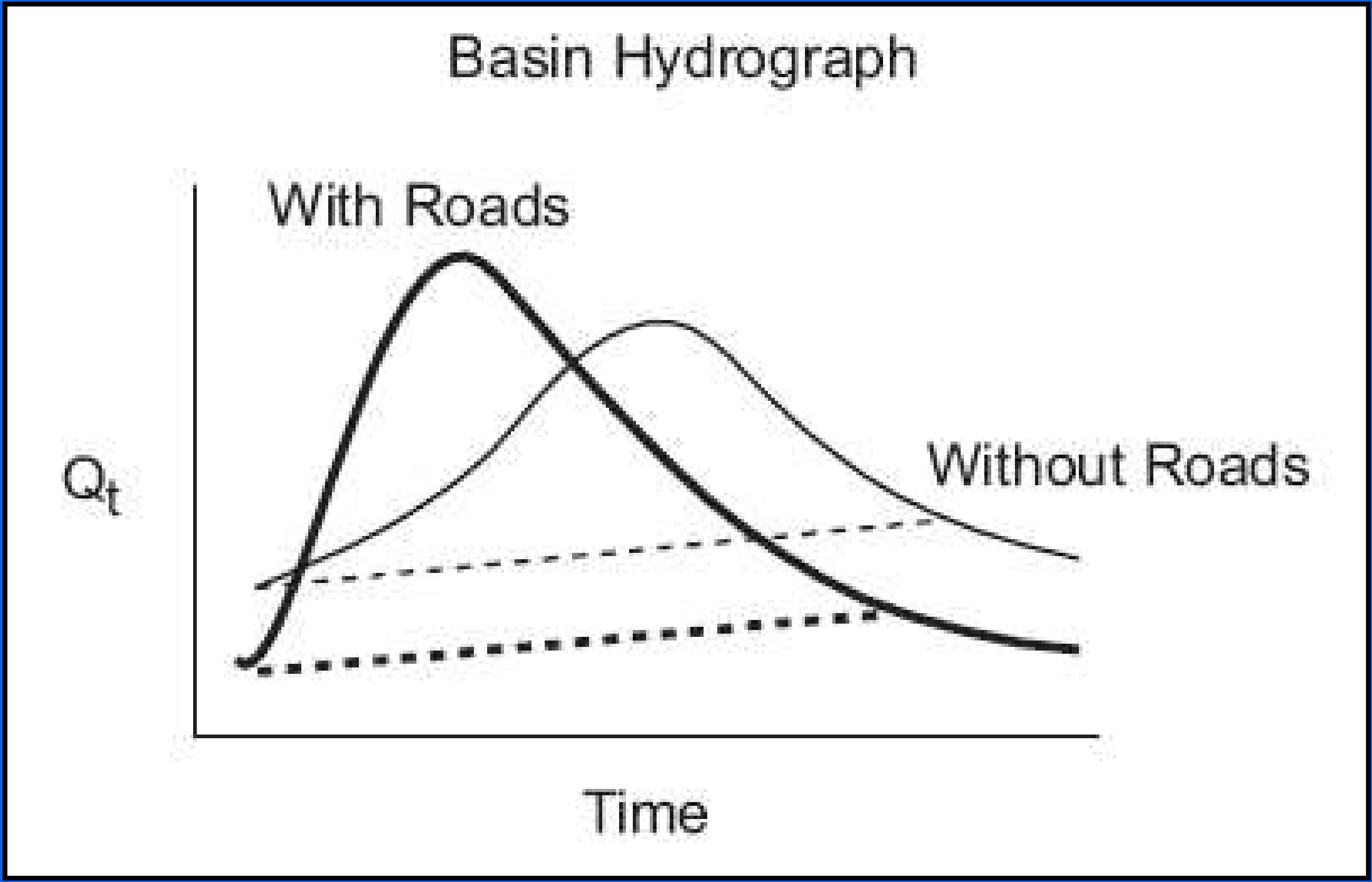
Road Segment Hydrology – Impacts to Low Order Channels

- Roads dominated by HOF can increase runoff in low-order channels by 10% (Ziegler et al., 2002);
- Roads dominated by ISSF can increase runoff in low-order channels by approximately 50% for snowmelt areas, up to 500% for rain-dominated areas (Megahan, 1972; Wigmosta and Perkins, 2001; Toman, 2004).
- Implications for scour of low order channels.

Road Segment Hydrology

- Only a small proportion of road segments contribute to peakflow augmentation (Wemple and Jones, 2003);
- Highly dependent upon bedrock topography.

Watershed Impacts – Do the Hydrologic Impact of Roads Translate Downstream?



(Wemple et al., 1996)

Hydrologic Effects of Roads at the Small Watershed Scale for Paired Watershed Studies in CA & PNW

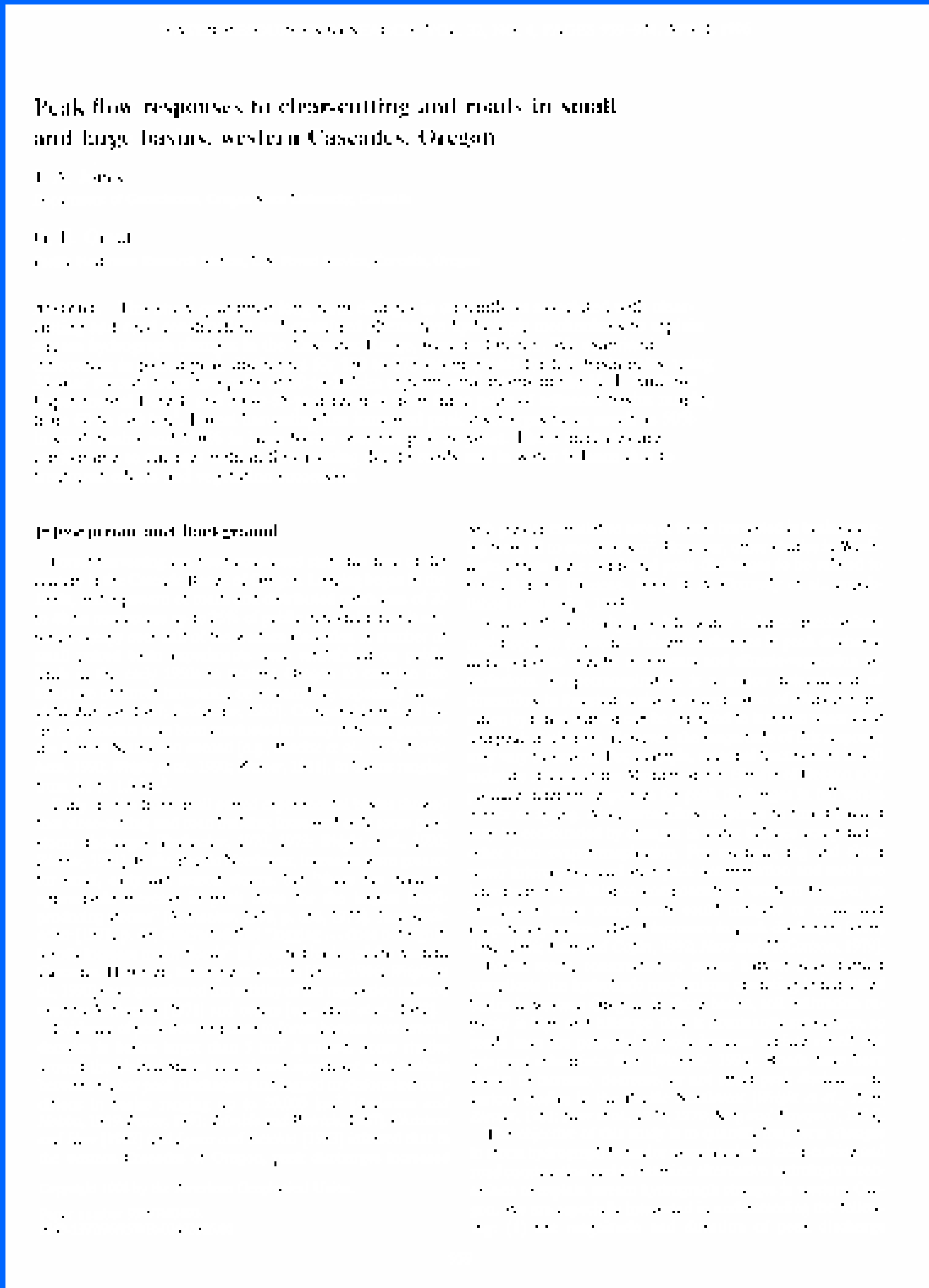
- Watershed areas ranged from 61-759 acres;

- Data from the HJ Andrews and Caspar Creek showed no increases in mean annual peak flow due to roads (Rothacher, 1973; Ziemer, 1981);

Forestry Effects on Peak Flows at the Small Watershed Scale

- No detectable effects of roads except when roads occupied more than 12% of watershed area.

- Forestry activities affect summer lowflows and early fall runoff events more than rainy season peak flows;


Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon

Introduction and background

JONES AND GRANT (1996)

- Looked at peak flow increases for small (60-101 ha) and large watersheds (60-600 km^{-2});
- Used different statistical methods than traditional paired watershed studies (i.e., ANOVA vs. ANCOVA).

Reanalysis of Paired Watershed Studies – Synergistic Effects

- Roads and harvest caused 50-100% increases in peak flow independent of peak flow size or spatial scale;
- **Interaction of roads and harvest greater than sum of parts.**

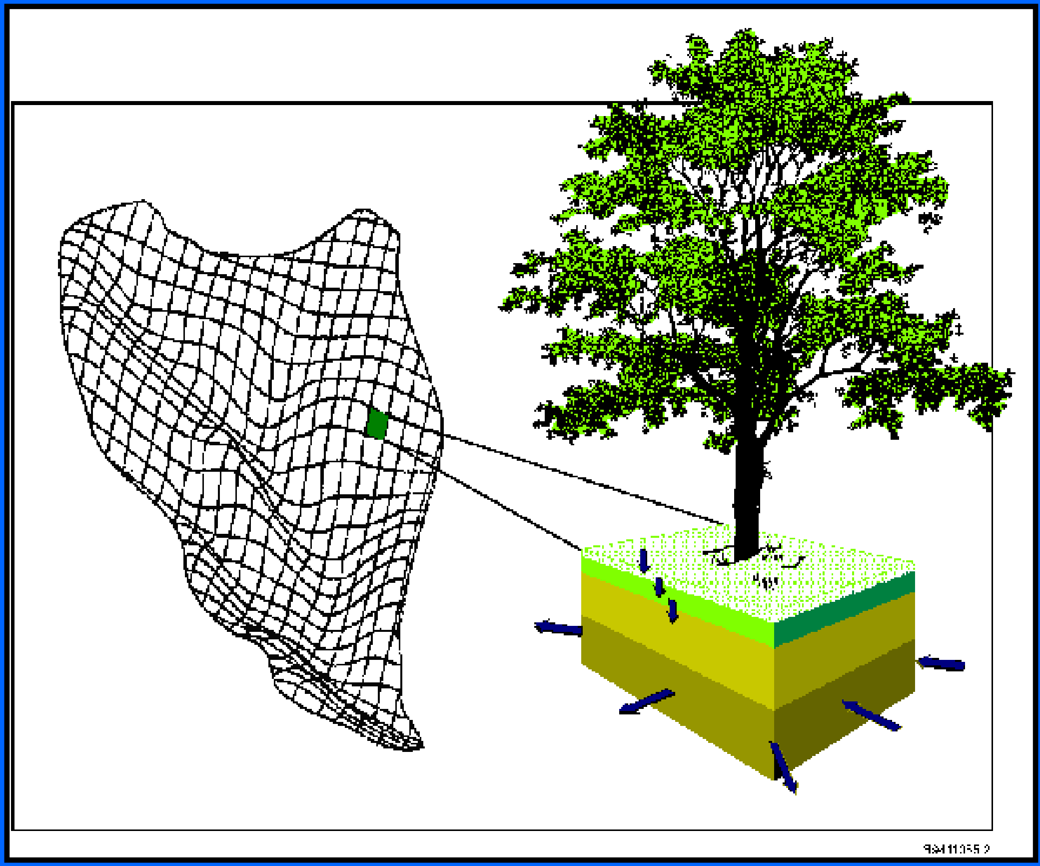
Reanalysis of Paired Watershed Studies - The Standoff

- Raised an uproar in forest hydrology community;
- Results were the product of inappropriate statistical methods;
- Jones and Grant backed off their assertions.

Results from Paired Watershed Studies Have LIMITATIONS

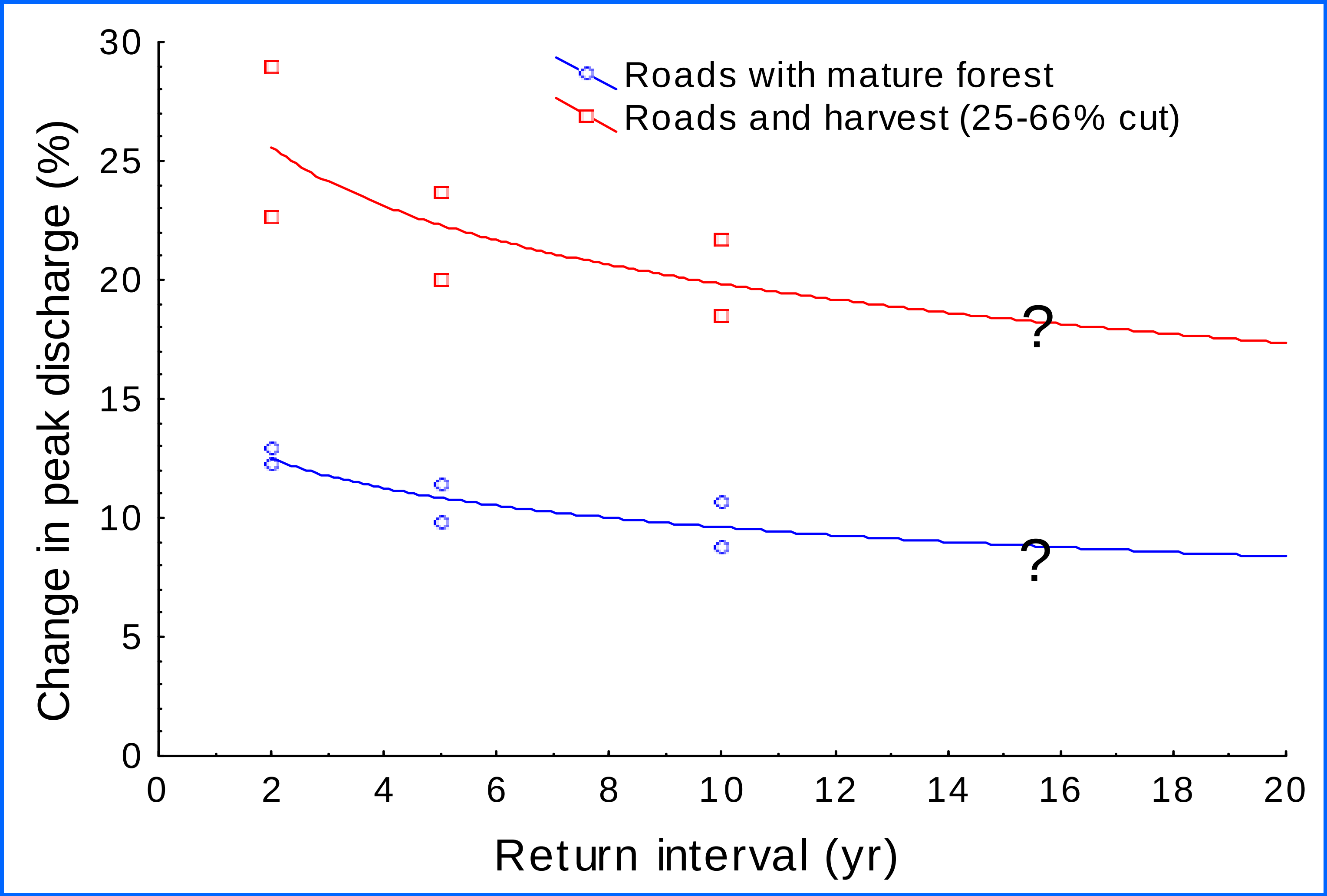
- Combination of harvest and road construction;
- Limited range of flow conditions;
- Poor pre-treatment calibration;
- Lack of treatment replication = poor statistical power.

Modeling Studies - Bowling and Lettenmaier, 2001



- Modeled two watersheds on Weyerhauser's Vail Tree Farm using DHSVM;
- Calibrated against known discharge records.

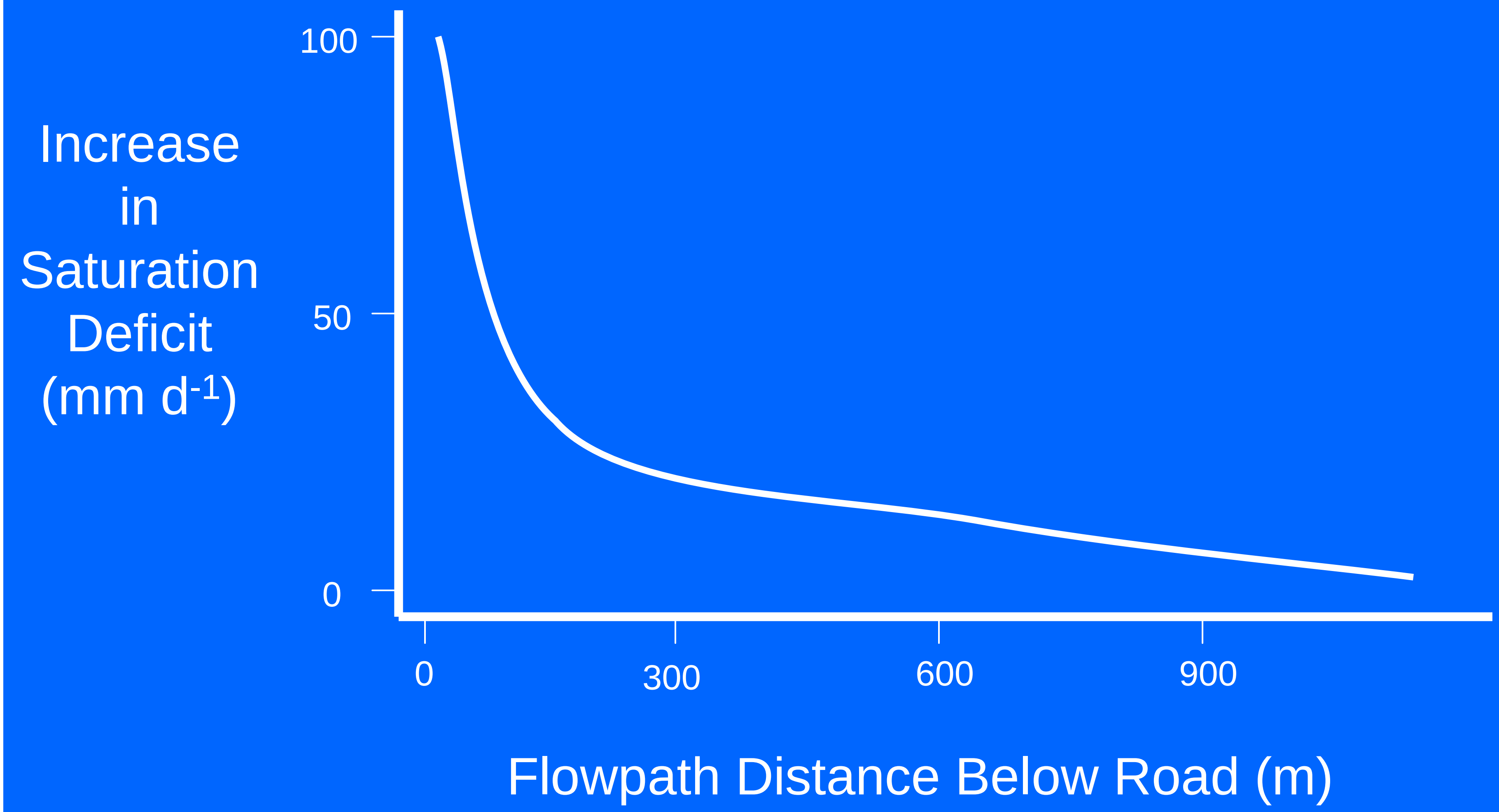
Road and Harvest Effect at Watershed Scale (0.9-1.1 mi^2)



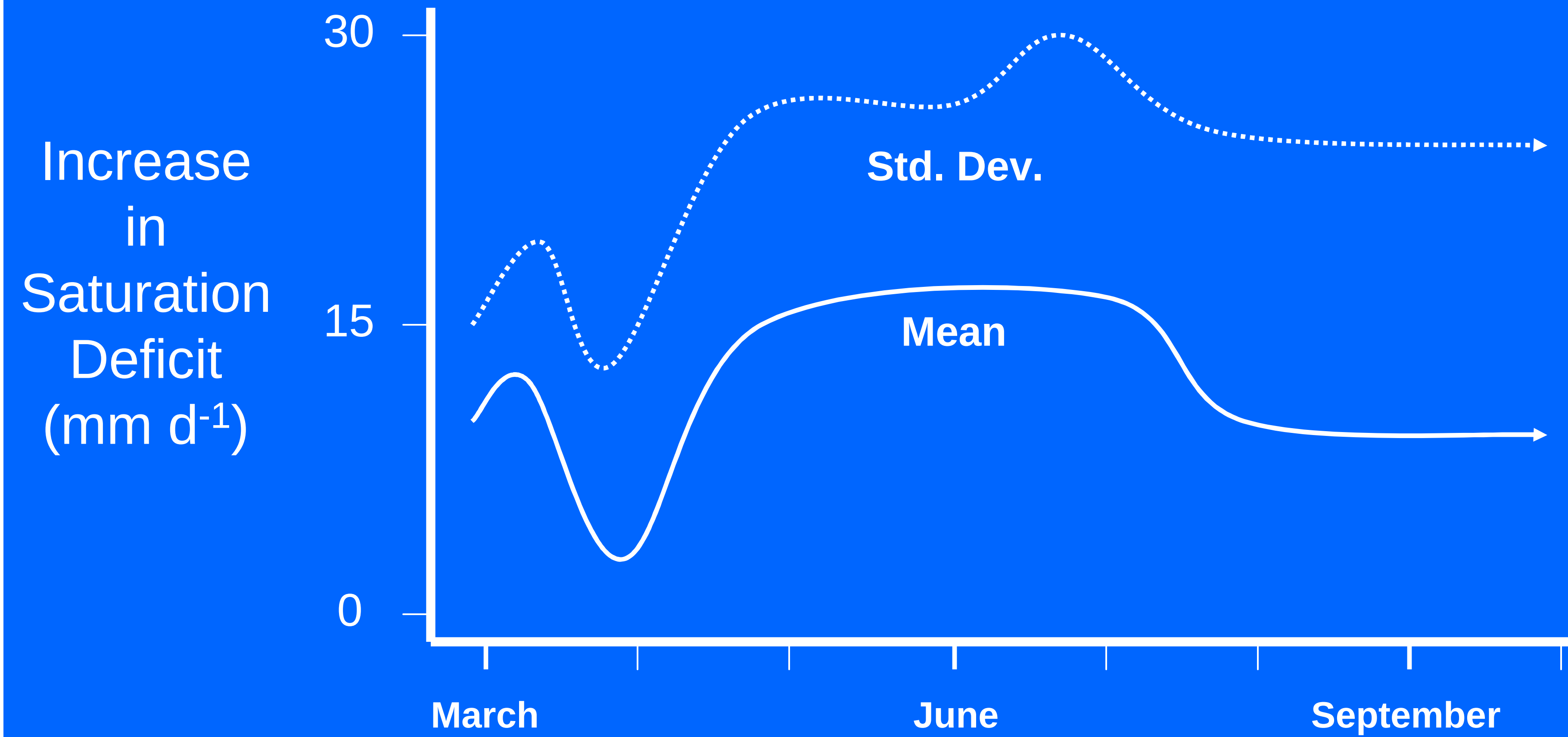
Bowling and Lettenmaier - Conclusions

- Effects of forest roads on peak flows equivalent to harvest;
- 11-12% increase per 2% of area disturbed by roads;
- Effects are additive rather than synergistic.
- Similar conclusions from LaMarche and Lettenmaier (2001)

Modeling Studies – Tague and Band, 2001



Modeling Studies – Effects on Summer Baseflow (Tague and Band, 2001)



How Do We Mitigate the Hydrologic Effects of Roads?

(Wemple, 2005)

Conclusions (1)

- Roads can dramatically alter runoff processes at the hillslope scale (e.g., plot and segment);
- Interception of SSF is the dominant mechanism of road runoff modification on steep, humid hillslopes (up to 95%);
- Road runoff can augment rising limb;

Conclusions (2)

- Majority of road runoff is from a small proportion of the road network;

- Magnitude of SSF interception dependent upon depth to impermeable zone, subsurface topography, arrangement of preferential flowpaths, and depth of road cut;

- Road runoff is delivered to the channel network at stream crossings, road-induced, and debris slide scars.

Conclusions (3)

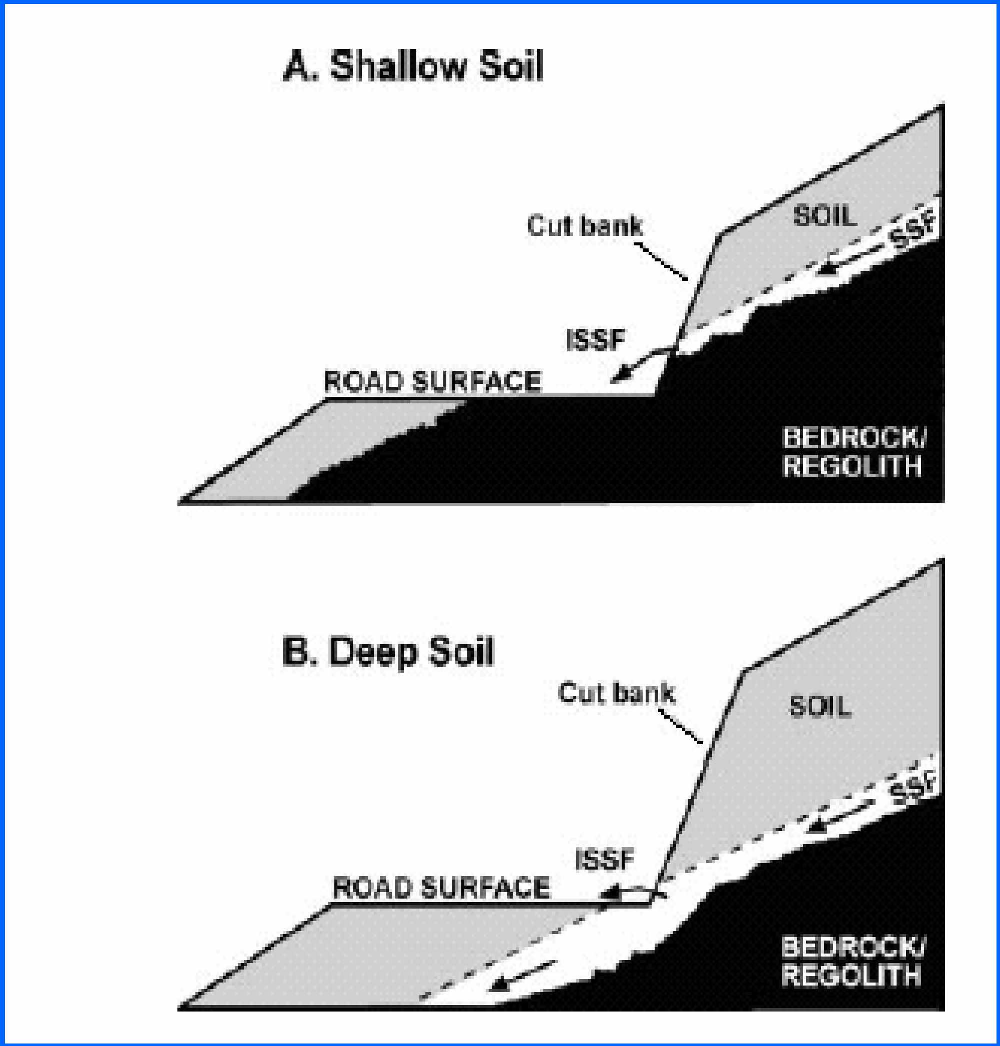
- Connectivity strongly controlled by climate and road design;
- Magnitude of road-induced peak flow impacts decrease in the downstream direction, but can still persist for at scales of up to approximately 20 km^2;
- Roads can account for half of management induced peak flows – effects are additive rather than synergistic.

Mitigation

Road ditch with intercepted groundwater

- Avoid excess stream crossings;
- Drain roads frequently;
- Minimize direct connectivity to channel network
- Minimize cutslope/flowpath interaction.

Mitigation



(Ziegler et al., 2002)

- Recognize areas where roads can intercept large quantities of SSF:
  - Shallow soils over bedrock;
  - Steeper slopes = higher cutbanks = more interception of SSF;
  - Presence of noticeable seeps or macropores.

Any Questions?